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Fracture Load Before and After Veneering Zirconia Posterior Fixed Dental Prostheses

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Keywords
FDPs; zirconia ceramic; CAD/CAM; fracture load; dental framework, ceramic veneering.

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The findings of this manuscript were presented at the Annual Meeting of the Spanish Society of Prosthodontics (S.E.P.E.S.), held in Granada, Spain in October 2012.

This study was supported by research grants from the Complutense University of Madrid (UCM), 3M España SA (no. 26-2005), and Ivoclar Vivadent SA (no. 481-2006), through the last author (Madrid, Spain).

The authors deny any conflicts of interest.

Accepted March 25, 2015

doi: 10.1111/jopr.12357

Abstract

Purpose: To evaluate the fracture load of 3-unit zirconia-based posterior fixed dental prostheses (FDPs) before and after veneering the frameworks.
Materials and Methods: Forty standardized stainless-steel master dies were fabricated (height: 5 mm, convergence: 6º, chamfer: 1 mm) and randomly screwed in pairs onto metal bases. The bases were randomly divided into two groups ($n = 20$ each) according to the zirconia CAD/CAM system used for constructing 3-unit structures for FDPs: group 1 (L): Lava All-ceramic, group 2 (Z): IPS e.max ZirCAD. Half of the zirconia structures per group were randomly selected and veneered, while the remaining half was left unveneered. The specimens were luted in standard fashion onto the stainless steel master dies using conventional glass ionomer cement. All specimens were tested for fracture load (FL). Specimens were subjected to a three-point bending test until fracture by applying an axial compressive load at the central fossa of the pontics with a universal testing machine at a 0.5 mm/min crosshead speed. Wilcoxon's rank-sum test and Weibull statistics were used for statistical analysis ($\alpha = 0.05$).
Results: L structures recorded significantly higher values of load to fracture than the Z group both before and after veneering. Within each ceramic group, no differences were found between unveneered and veneered frameworks.
Conclusions: Although further studies are necessary to corroborate these findings, both zirconia systems could be recommended for restoring posterior teeth on the basis of the fracture load values recorded in this experiment (>1000 N). The veneering procedure did not affect the overall load to fracture in any group.

Until recent years, metal ceramic restorations were the most recommended treatments in the area of fixed dental prostheses (FDPs); however, esthetic demands and research in biocompatibility have resulted in the development of metal-free restorations. The discovery of ceramics for dental applications was one of the most important advances in prosthodontics in the twentieth century. Over the two last decades, the use of all-ceramic prostheses has greatly increased, partly due to remarkable advances in materials science and technology.[1]

Major concerns have focused on improving the cosmetic results and fracture resistance of all-ceramic restorations. For these reasons, zirconia-based materials have played a key role in the fabrication of frameworks for FDPs. Zirconia offers high toughness, fracture load, and reliability owing to its property of tetragonal-to-monoclinic phase transformation, called "transformation toughening."[2,3] Nonetheless, zirconia is highly opaque, so the framework material constructed with CAD/CAM technologies[1,4,5] must be coated with feldspathic ceramic to achieve a natural appearance.[6]

Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP)-based prostheses could offer an alternative to metal-ceramic prostheses, as Y-TZP has the potential to withstand occlusal forces in the molar region.[7] However, there are few studies of posterior FDPs, and the differences observed in the outcomes have been attributed to the fabrication procedures to which the specimens were submitted.

The mechanical behaviors of framework and veneer materials are usually evaluated separately, providing information on the fracture resistance of each component.[4] However, it is important to understand the influence of the veneer ceramic on the mechanical performance of zirconia frameworks. During the veneering procedure, the mechanical properties of zirconia can be affected, because the structures are exposed to moisture and relatively high temperatures, and previous research has shown that fracture resistance was significantly reduced or increased after veneering.[8-10] Given that the findings often differ, depending on the zirconia material used, it may be of interest to investigate this aspect.

The purpose of the present experiment was to assess the load to fracture of 3-unit zirconia-based posterior FDPs fabricated with two zirconia CAD/CAM systems before and after veneering the frameworks. The null hypothesis stated that no differences in load to fracture would be found between the two zirconia systems, and that veneering would have no influence on fracture load.

Materials and methods

Forty standardized stainless-steel master dies (height: 5 mm, convergence: 6º, chamfer: 1 mm) were fabricated in the Faculty of Physical Science of the Complutense University of Madrid (UCM, Spain). The dies were randomly screwed in pairs onto metal bases, which were in turn randomly divided into two groups ($n = 20$ each) according to the zirconia CAD/CAM system used for constructing 3-unit structures for FDPs: group 1 (L): Lava all-ceramic system (3M ESPE, Seefeld, Germany); group 2 (Z): IPS e.max ZirCAD system (Ivoclar Vivadent, Schaan, Liechtenstein).

Specimens from each ceramic group were also randomly divided into two experimental subgroups ($n = 10$ each) as follows: subgroup 1 (F): unveneered frameworks; subgroup 2 (T): veneered frameworks. Both zirconia systems used a laser scanner (L group: Lava Scan; 3M ESPE; and Z: CEREC inEos; Sirona Dental, Salzburg, Austria). All structures were designed with a thickness of 0.5 mm, a connector size of 3 mm × 3 mm and a space of 50 μm for the luting agent. The frameworks were milled prior to sintering, and the design was enlarged by 20% to offset post-sintering shrinkage.

Half of the frameworks per experimental ceramic group were veneered with compatible hand-layered feldspathic ceramic. The manufacturers' guidelines were followed in each group as described below.

In case of the L frameworks, a 0.1-/0.2-mm film of specific liner (Zirconia Overlay Porcelain for Lava Frame; 3M ESPE) was applied and submitted to a firing cycle of 16 minutes at 820ºC in a ceramic oven (Programat P500/G2; Ivoclar Vivadent AG). Subsequently, the structures were covered with the corresponding veneering ceramic (Lava Ceram; 3M ESPE) through a stratification technique with two layers of dentine ceramic that underwent two independent cycles of 15 minutes each at 810 and 800ºC. Next, one layer of enamel ceramic was fired at 800ºC for 15 minutes. Finally, the glaze firing was made at 790ºC for 16 minutes.

For the Z structures, a 0.1-/0.2-mm film of specific liner (IPS e.max ZirLiner; Ivoclar Vivadent) was applied and submitted to a firing cycle of 16 minutes at 750ºC in a ceramic oven (Jelrus Vista/Wizard; Jelrus, Dayton, OH). Then, frameworks were coated with the corresponding veneering ceramic (e.max Ceram, Ivoclar Vivadent) through a stratification technique by firing two layers of dentine ceramic and one layer of enamel ceramic at the temperature of 755ºC for 13 minutes per cycle. In this group, the glaze firing was performed at 730ºC for 14 minutes.

All specimens were luted in standard fashion onto the stainless-steel master dies by using conventional glass ionomer cement (Ketac-Cem EasyMix; 3M ESPE). The axial surfaces of the abutments were varnished with a thin layer of cement before inserting each FDP structure. A customized clamp was designed to keep a constant 10 N seating pressure for 10 minutes.

Each FDP was subjected to a three-point bending test until fracture using a universal testing machine (UTM) (ME 405/10; SERVOSIS SA Pinto, Madrid, Spain) at a 0.5 mm/min crosshead speed. This experiment was developed at the National Center for Metallurgical Research (CENIM, CSIC, Madrid, Spain). Axial compressive loads were exerted by sliding a cone-shaped stainless-steel bar (length: 12 mm) finished in a rounded tip (diameter: 1mm) adapted to the UTM. This customized load piston was perpendicularly applied at the central fossa of each pontic until the total fracture of the restoration, defined as a sharp decrease in the stress plot, in addition to evidence of visible signs of fracture. The load cell used for this eassay was of 10 Tm, with a cell of 2000 kg, and a scale of 1/5. The results were recorded using inbuilt software for the testing machine, and force (N)-displacement (mm) curves were automatically created. All of the materials were handled following the manufacturer's recommendations, at room temperature (RT: 23.0 ± 1.0ºC), and relative humidity (50 ± 5%).

Fracture load values were analyzed using Wilcoxon's rank-sum test. To aid the accurate interpretation of data, the parameters of the Weibull distribution, Weibull modulus (m), and the characteristic fracture load ($\sigma 0$) were estimated by maximum likelihood at 95% CI. The cutoff value for statistical significance was set at $\alpha = 0.05$. Statistical package software (SAS 9.4; SAS Institute Inc., Cary, NC) was used for data analysis.

Results

Table 1 and Figures 1 and 2 display the mean fracture load values for the experimental groups. Results of Wilcoxon's rank-sum test are as follows. When the overall load to fracture was explored, the L group (2934.12 ± 203.72 N) achieved significantly higher values ($p = 0.0016$) than did the Z group (2068.65 ± 90.52 N). The L unveneered structures (3286.90 ± 984.37 N) recorded significantly higher values of load to fracture ($p = 0.006$) than did their Z unveneered counterparts (2063.22 ± 522.89 N) (Fig 3). After the frameworks were veneered, significant differences were also observed between the ceramic groups ($p = 0.04$), with the L specimens showing the highest values (2581.05 ± 711.48 N) (Fig 4).

Pooling the L and Z groups together, unveneered and veneered structures resulted in statistically comparable overall load to fracture (2675.06 ± 991.24 and 2327.56 ± 584.75 N, respectively; $p = 0.4$). Moreover, unveneered and veneered frameworks performed equally well in terms of load to fracture within each ceramic group ($p = 0.14$ for L group, $p = 0.79$ for Z group). In all cases, the fracture occurred at the connector level (Figs 3 and 4).

Table 1 Weibull statistics of fracture load

	m = Weibull shape				σ0 = Weibull scale			
	Estimate	SD error	Lower	Upper	Estimate	SD error	Lower	Upper
LF	4.0598	1.0398	2.4575	6.7069	3634.6568	298.2575	3094.67	4268.86
LT	4.1162	0.9785	2.5831	6.5592	2839.5544	230.8228	2421.34	3329.9904
ZF	4.2427	0.9723	2.7075	6.6485	2261.2089	179.1265	1936.02	2641.0122
ZT	8.6937	2.0947	5.4214	13.9410	2189.5944	84.4650	2030.14	2361.5617

*LF: average fracture load of the Lava frameworks. LT: average fracture load of the Lava veneered structures. ZF: average fracture load of the IPS e.max ZirCAD frameworks. ZT: average fracture load of the IPS e.max ZirCAD veneered structures.

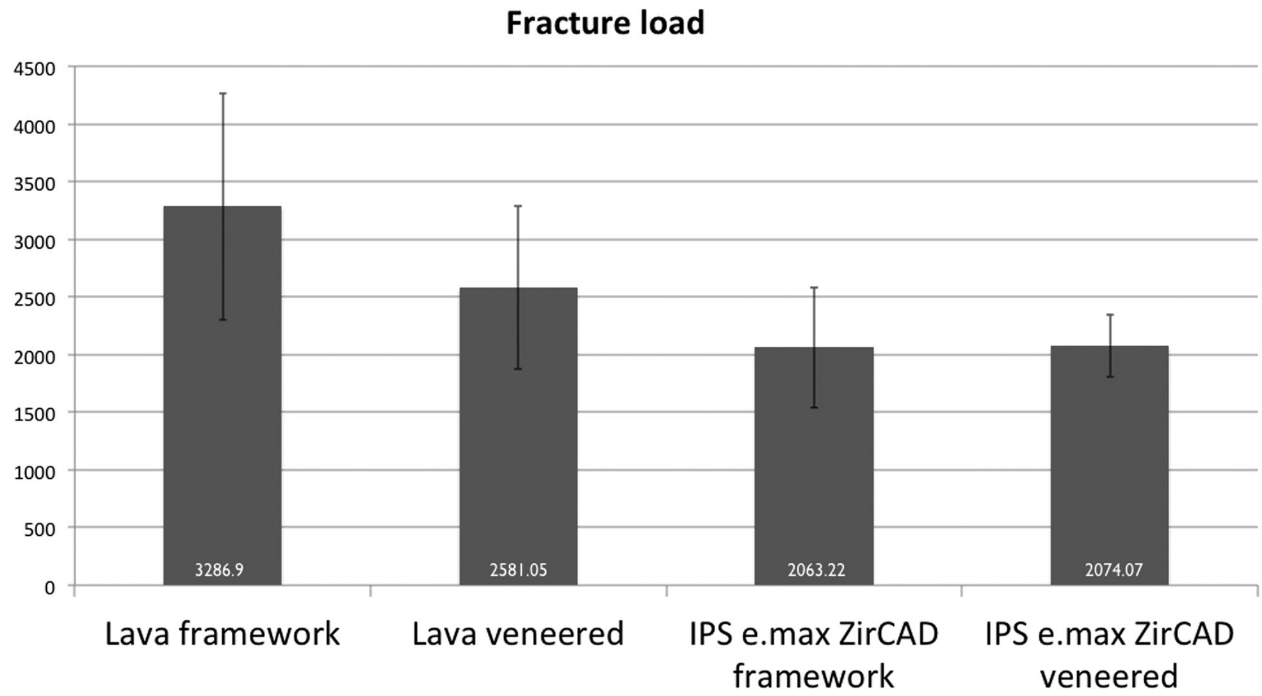


Figure 1 Average fracture load values (N) of the tested structures before and after veneering.

Regarding Weibull statistics, upper and lower confidence bounds were applied on the curves to look for overlap to investigate the existence of significant differences among the Weibull distribution parameters. Although the characteristic strength ($\sigma 0$) yielded significant differences, the Weibull distributions overlapped to some extent. Thus, no significant differences were found among unveneered and veneered structures within each zirconia group; however, significant differences were detected among L and Z unveneered structures and also between L and Z veneered frameworks.

Discussion

This study investigated the load to fracture of 3-unit zirconia-based posterior FDPs fabricated with two zirconia CAD/CAM systems before and after veneering the frameworks. The results require partial rejection of the null hypothesis, because the fracture load was not affected by the veneering procedure in any of the tested groups, but was dependent on the zirconia system (Table 1; Figs 1 and 2).

The values reported for normal occlusal bite forces vary greatly and depend upon gender, age, and whether they were measured in the anterior or in the posterior region; however, the forces applied in cases of parafunction can be as high as 1000 N; therefore, dental restorations should support loads greater than 1000 N.[6,11] Zirconia materials have been considered able to withstand posterior physiologic loads; however, concerns still remain on their use for patients with parafunctional habits.[12]

In the current experiment, both zirconia systems exhibited fracture resistance values greater than 1000 N. Although veneering resistance was not the focus of the study, it was observed that the veneering fracture started at values higher than 1000 N in all cases. These results are in agreement with those of a previous investigation on Lava FDPs[13] that recommended this CAD/CAM system for clinical use; however, the fracture load values in the present study were higher than those

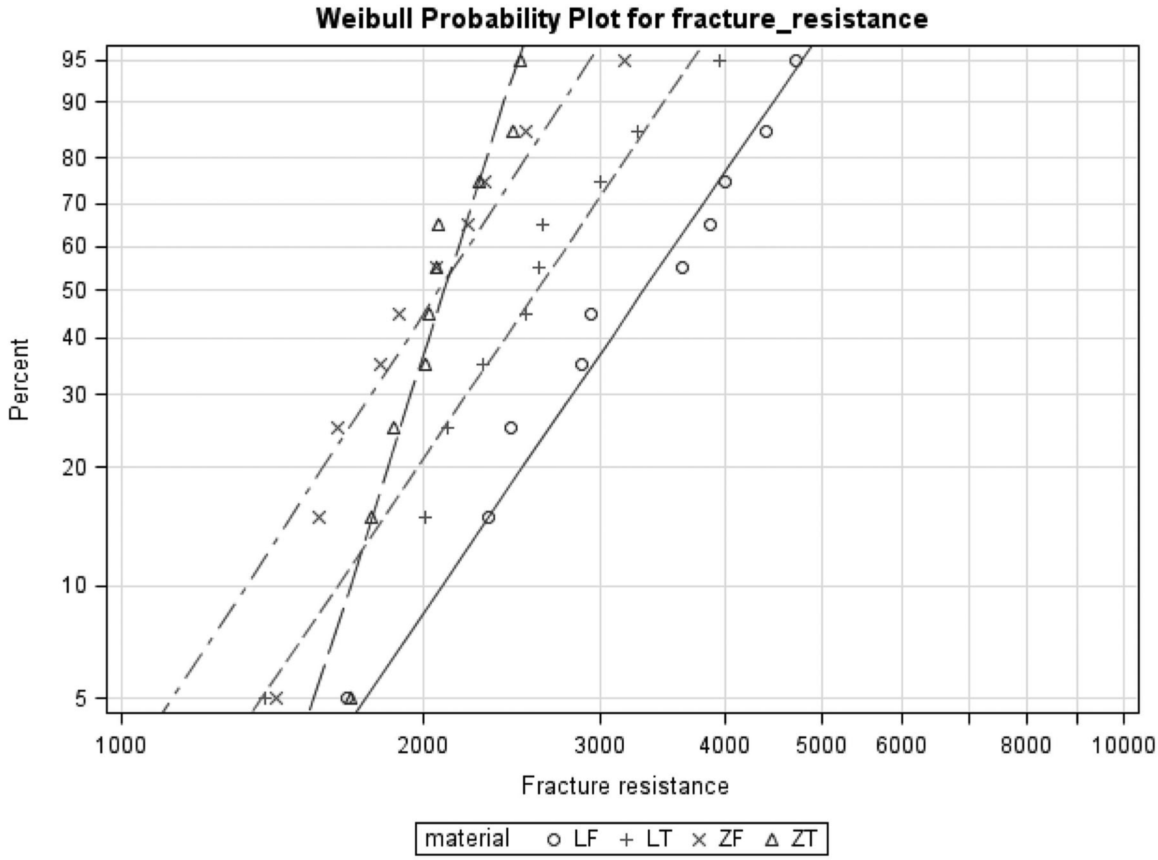
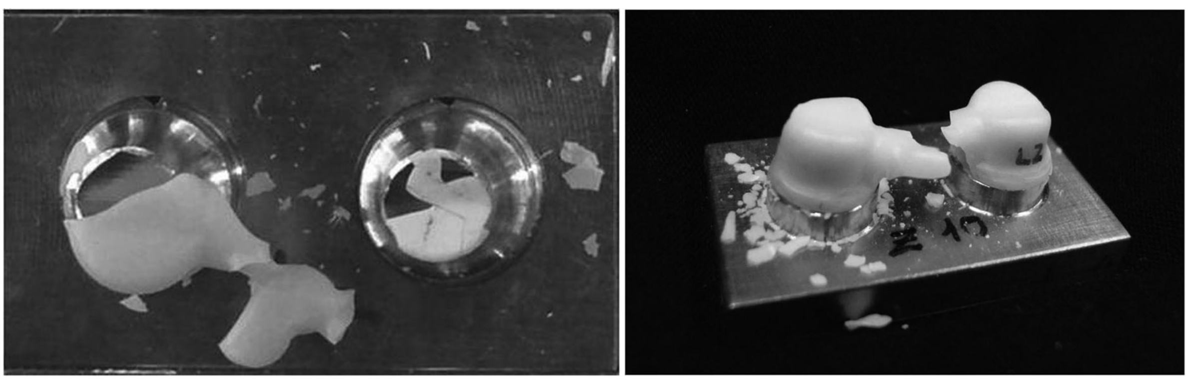


Figure 2 Weibull probability plot of the fracture resistance of the unveneered and veneered frameworks (*LF: average fracture load of the Lava frameworks. LT: average fracture load of the Lava veneered structures. ZF: average fracture load of the IPS e.max ZirCAD frameworks. ZT: average fracture load of the IPS e.max ZirCAD veneered structures).

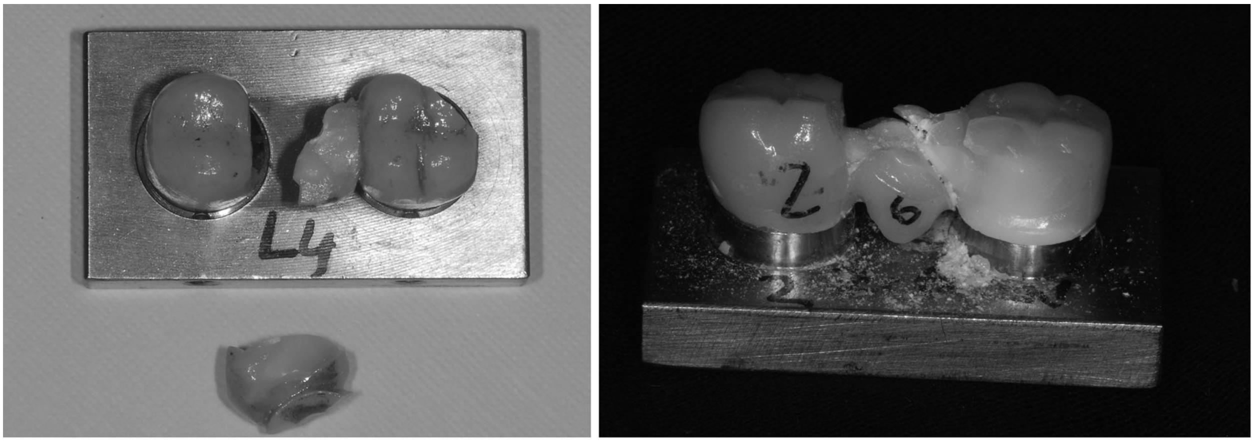


A B

Figure 3 Completely fractured unveneered frameworks. A. L specimen. B. Z specimen.

previously reported. This is most likely because the measured values occurred at the total fracture of the specimens. The lack of in vitro studies of posterior FDPs fabricated with the IPS e.max ZirCAD system makes comparisons difficult.

The methods of our in vitro research were chosen to reflect the clinical situation, and the design of the specimens conformed to anatomical shapes and had similar dimensions to those of FDPs in clinical use, as previously reported.[14] However, one of the limitations of the study was that the specimens were tested under compressive loads without reproducing the typical cyclic loading conditions of the oral environment. In this regard, it is well known that strength degradation occurs in



A B

Figure 4 Completely fractured veneered specimens. A. L specimen. B. Z specimen.

zirconia ceramics when they are used in a water environment, due to the chemical reaction of yttria with water, leading to the depletion of yttria.[2,3,15] Nevertheless, the fracture patterns of specimens tested in water seem to exhibit slow crack growth before catastrophic fracture.[15]

In one of the referenced articles,[15] the type of environment (i.e., water vs. inert environment) yielded no significant differences in fracture toughness, while other studies reported differences depending on the dry/wet testing conditions.[16,17] Therefore, this aspect deserves further investigation, but it was not the aim of the current experiment.

It has been debated whether FDP frameworks for testing should be veneered.[6] In the current study, no differences in fracture resistance were observed before or after veneering for either zirconia system (Table 1; Figs 1–4). These results contrasted with those of previous experiments that demonstrated that the phase transformation mechanism weakened the frameworks, increasing the monoclinic phase content from 2% to 10% after veneering.[8,18,19] Nevertheless, another investigation found that the veneering procedure could increase the fracture resistance and that this influence seemed to be dependent on the type of zirconia-based material used.[10] Our study detected differences in the load to fracture between the L and Z groups, with higher values for the L specimens (Table 1; Figs 1 and 2).

On the one hand, these findings may indicate that the mechanical properties of the zirconia materials tested were not affected by surface treatment and that the veneering porcelain did not seem to affect the total fracture resistance. On the other hand, the differences observed between both ceramic groups (Table 1; Figs 1 and 2) suggest that the temperatures and cycles programmed to obtain the CAD/CAM-based restorations could have affected their final resistance. This should be further analyzed by comparing the influence of those parameters in the fracture load of more of zirconia systems.

The Weibull analysis is recommended to describe the strength variation of brittle dental materials.[20-22] Lower Weibull moduli (shape parameter) designate greater variability and, therefore, less reliability in the strength, which may be attributable to flaws and/or defects in the tested material.[23,24] The Weibull modulus values of most dental ceramics usually range around 5 to 15,[20,24] which is in agreement with our results (Table 1). In the Weibull test, the characteristic strength (scale parameter) characterizes the 63.21 percentile of the strength distribution.[23] Several estimation methods may be applied to explore the Weibull parameters. One is the maximum likelihood estimation approach, which was selected in this study. It is more often preferred because the 90% or 95% CI on the estimates of the Weibull parameters are considerably tighter than those of linear regressions.[22,24] In our investigation, significant differences were only verified in the scale parameter (Table 1). Nonetheless, as in previous research,[23-25] the Weibull statistics were run together with a test that compared the outcomes among independent groups to provide a more complete and consistent analysis.

In general, it would be possible to conclude that Lava and IPS e.max ZirCAD FDPs could constitute alternative treatments to classic metal ceramic restorations. Nonetheless, more studies on fracture resistance using cyclic loading under wet conditions in bigger samples accompanied by long-term follow-up clinical trials are required to better understand the causes of the fractures and the origin and expansion of the cracks in the zirconia framework, as well as between the zirconia structures and the veneering ceramic. Such studies, together with those of misfit[26-30] and cementation[28,31-34] of CAD/CAM zirconia-based restorations give valuable information on the performance of this type of prosthesis, thus playing a key role in clinical decision-making and treatment success.[35]

Finally, our results should be interpreted with caution, as the small numbers of specimens is a limitation of the study. The flexural strength of ceramics is probabilistic in nature and, consequently, larger numbers of specimens in future investigations would reduce the statistical uncertainty with its determination.

Conclusions

In view of the study results, the following conclusions may be drawn:

1. Both ceramic systems had clinically acceptable fracture load values of greater than 1000 N.
2. The Lava system demonstrated significantly higher load to fracture than the IPS e.max ZirCAD before and after veneering the zirconia cores.
3. The veneering procedure did not affect the overall load to fracture in any group.
4. Despite the promising results reported, further in vitro and in vivo studies are required to support our findings before giving any definitive clinical advice.

Acknowledgments

The authors would like to thank the Protesis SA and Poveda SL dental laboratories for their technical advice and for manufacturing the FDPs. We also would like to thank Dr. Guillermo Caruana, from the National Centre for Metallurgical Research, for his assistance with the loading of the specimens; and Drs. Ricardo García and Carmen Bravo from the Centre for Data Processing, Computing Service for Research Support of the Complutense University of Madrid (UCM), for assistance with the statistical analysis.

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